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U. S. DEPARTMENT OF AGRICULTURE.

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B. T. GALLOWAY, *Chief of Bureau.*

THE VARIABILITY OF WHEAT VARIETIES IN RESISTANCE TO TOXIC SALTS.

BY

L. L. HARTER,

SCIENTIFIC ASSISTANT, LABORATORY OF PLANT BREEDING.

VEGETABLE PATHOLOGICAL AND PHYSIOLOGICAL INVESTIGATIONS.

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B. T. GALLOWAY,
Pathologist and Physiologist, and Chief of Bureau.

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J. ARTHUR LE CLERC,[c] *Physiological Chemist, Cereal Investigations.*
T. D. BECKWITH, *Expert, Plant Physiology.*

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[a] Detailed to Seed and Plant Introduction and Distribution.
[b] Detailed to Bureau of Chemistry.
[c] Detailed from Bureau of Chemistry.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., May 1, 1905.

Sir: I have the honor to transmit herewith a technical paper entitled "The Variability of Wheat Varieties in Resistance to Toxic Salts," and to recommend that it be published as Bulletin No. 79 of the series of this Bureau.

This paper was prepared by Mr. L. L. Harter, Scientific Assistant in the Laboratory of Plant Breeding, Vegetable Pathological and Physiological Investigations, and was submitted by the Pathologist and Physiologist with a view to publication. The subject-matter of the bulletin will be of interest to experimenters who are working on the problems of securing alkali-resistant strains of agricultural crops.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

The main object of the accompanying paper is to prove that different varieties of a single species behave differently in the presence of the harmful salts that are present in the so-called alkali soils of the western United States. The work has been done with varieties of wheat on account of the great importance of that crop in the region indicated and because, being grown under a great diversity of conditions as regards climate and soil, wheat varieties would be expected to differ much among themselves in their power to withstand the effect of excessive amounts of salts in the soil, just as they differ widely in their capability of withstanding drought, cold, and parasites.

The experiments were made with young seedlings, their roots being exposed for periods of twenty-four hours to the action of pure solutions of the salts used, the greatest strength of solution in which the root tips could survive being taken as representing the limit of endurance of each variety to each salt. The salts used were the carbonate, bicarbonate, sulphate, and chlorid of sodium, and the sulphate and chlorid of magnesium. These are salts that are generally present in the largest quantity in alkali soils. Nine varieties of wheat, both from the Old World and the New, representing widely different climates and soils, were compared.

It was found that the varieties differed greatly in their ability to withstand the poisonous action of the salts used. This was more strikingly brought out in the case of some salts than of others. To magnesium sulphate, for example, some varieties are three times as resistant as are others. Tables are given in the following paper showing the limit of concentration of each of the nine varieties for each of the six salts. It was also clearly demonstrated that the different individuals of each variety differ much in resistance, and the limits of the varieties as established are only the means of the limits for all the individuals tested. Analyses of the ash of each lot of seed used were obtained from the Bureau of Chemistry, but no correlation could be shown between ash composition and resistance to action of toxic salts. On the other hand, it was clearly demonstrated that

with few exceptions the varieties that have originated in arid regions, where the soils are usually more saline than in humid regions, are those that are most resistant to pure solutions of sodium and magnesium salts. Three varieties of southeastern Russia, with one exception, were found to be the most resistant of all those tested.

It is believed that the laboratory work upon which this paper is based has a direct practical bearing, as it gives us an indication of what varieties are most likely to succeed in arid regions where the soils are more or less salty. Furthermore, as some one salt—e. g., sodium chlorid—sometimes strongly predominates in the soils of a particular region, and as these experiments show clearly that, while one variety may be more resistant than another to sodium chlorid, the second is often more resistant than the first to sodium carbonate or to magnesium sulphate, we can thus obtain information as to which of the many varieties of a great crop can be sown with the best chance of success upon a given type of alkali soil. In other words, a few weeks of simple laboratory experiment may save years of costly trial in the field, although, of course, the water-culture experiments can not be considered as giving more than an indication of what we can expect each variety to do, and the final test must be the growing of the crop upon a practical scale.

The great individual variability in resistance brought out in these experiments shows that not merely have we found a guide as to which of existing varieties are best adapted to different types of saline soils, but that there is an excellent opportunity for increasing their resistance by selecting seed from the most resistant individuals. The present investigation affords further evidence that it is practicable to apply plant-breeding methods to the "alkali problem" and adapt crops by selection to the unfavorable conditions presented by soils that contain excessive amounts of soluble salts.

A. F. Woods,
Pathologist and Physiologist.

Office of Vegetable Pathological
and Physiological Investigations,
Washington, D. C., April 26, 1905.

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THE VARIABILITY OF WHEAT VARIETIES IN RESISTANCE TO TOXIC SALTS.

INTRODUCTION.

It has been shown quite conclusively in recent years that different species and genera differ very much in their ability to resist the influence of toxic salt solutions. Numerous investigations of the action of acids and salts upon plants have been made, especially during the last four or five years. Investigations of this nature are not only of great scientific interest, but promise in some cases to be of considerable practical importance. One phase of this subject which is especially interesting from this latter point of view is that of the relation of plants, particularly cultivated plants, to the components of the saline or alkaline soils that are so common in the arid part of the United States and of many other parts of the world.

A preliminary investigation of this phase of the subject was made by Messrs. Kearney and Cameron,[a] who showed by a large number of experiments on *Lupinus albus* and *Medicago sativa* that the death limit of the root tips was very different for different salts. For instance, the limit for *Lupinus albus* in sodium chlorid was found to be 0.02 of a normal solution, and in magnesium sulphate 0.00125. For *Medicago sativa*, in mixed solutions containing an excess of two calcium salts, the limit was 0.35 in magnesium sulphate and 0.20 in sodium chlorid.[b]

Much work has been done in comparing different botanical species as to their resistance to the effect of salt solutions,[c] but the compara-

[a] Report No. 71, U. S. Dept. of Agriculture (1902).

[b] Messrs. Kahlenberg and True, who have done considerable work along this line, particularly with salts and acids, give some very interesting results. They found (On the Toxic Action of Dissolved Salts and Their Electrolytic Dissociation, Bot. Gaz., 22:81, 1896) that *Lupinus albus* would just survive in $\frac{1}{51200}$ gram mol. per liter of copper salts. They found the same limits with ferrous sulphate ($FeSO_4$), nickel sulphate ($NiSO_4$), and cobalt sulphate ($CoSO_4$), but for mercuric chlorid ($HgCl_2$) $\frac{1}{12800}$, and mercuric cyanid ($HgCn_2$) only $\frac{1}{102400}$ gram.

[c] The experiments of Heald (On the Toxic Effect of Dilute Solutions of Acids and Salts upon Plants, Bot. Gaz., 22:125, 1896), and later those of Moore and Kellerman, are among the most interesting in this connection.

Heald, in a series of experiments resembling those of Kahlenberg and True, obtained some valuable results with *Cucurbita pepo*, *Zea mays*, and *Pisum sati-*

tive resistance of different varieties, or races, of a single species has received little attention.[a]

During the autumn of 1903, and again in 1904, the writer had occasion to repeat, at the Department of Agriculture, Washington, D. C., the experiments previously conducted by Kearney and Cameron with

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vum. He found the limit of *Pisum sativum* to be $\frac{1}{51200}$ gram mol. per liter for copper sulphate ($CuSO_4$) as the strength which will barely permit the roots to live, and that for *Zea mays* to be $\frac{1}{25600}$. He obtained results with various salts, but this will suffice to show the variability between plants widely separated in relationship.

Moore and Kellerman (A Method of Destroying or Preventing the Growth of Algæ and Certain Pathogenic Bacteria in Water Supplies, Bul. 64, Bureau of Plant Industry, U. S. Department of Agriculture, 1904) say:

In dealing with algæ the toxic concentration varies greatly for different genera, even for different species of the same genus. Nägeli demonstrated the extreme sensitiveness of *Spirogyra nitida* and *S. dubia* to the presence of copper coins in the water. *Oscillatoria*, *Cladophora*, *Œdogonium*, and the diatoms succumb in six hours to a copper-sulphate solution of 1 to 20,000 and in two days to 1 to 50,000 according to Bokorny. * * * According to Ono, weak solutions of the salts of most of the metals encourage the growth of algæ and fungi. Mercury and copper, however, at 0.00005 per cent and 0.00001 per cent, respectively, distinctly inhibit growth. This was the case with *Stigeoclonium*, *Chroococcus*, and *Protococcus*.

Moore and Kellerman have obtained results with algæ which serve very well to illustrate the variability of these organisms in the presence of the toxic copper sulphate. They found that with this salt 1 to 25,000, 1 to 75,000, and 1 to 100,000 were sufficient to kill *Raphidium polymorphum* in four days, *Desmidium swartzii* in three days, and *Navicula* sp. in five days, respectively. One part of salt to 300,000 of water and 1 to 1,000,000 were fatal to *Conferva bombycinum* in three days and *Synura uvella* in a few minutes. *Closterium moniliferum* was killed in four days in a 1 to 500,000 solution, and *Anabæna flos-aquæ* in a 1 to 3,000,000 solution in seventy-two hours. The most sensitive of all was *Uroglena americana*, practically all of which were killed in a 1 to 10,000,000 solution in sixteen hours.

[a] J. F. Breazeale informs the writer that in water-culture experiments in the laboratory of the Bureau of Soils, United States Department of Agriculture, he has found a very wide variation in the development of seedlings of different varieties of wheat when grown in the same artificial nutrient solutions and also aqueous extracts of soil, and W. H. Heileman, in the same laboratory, has shown very similar results to those presented in this investigation when using different varieties of wheat in pot cultures of natural and artificial alkali soils. It has also been shown that the vigor and rate of germination of seeds of different varieties are very different when previously soaked in any given solution of an electrolyte.

Cameron and Breazeale (The Toxic Action of Acids and Salts on Seedlings, Journal Phys. Chem., vol. 8, No. 1, p. 1, Jan., 1904) have shown a wide variation in the toxic action of different salts and acids on seedlings of plants widely separated in relationship.

From certain points of view, especially as bearing on current chemical theories, the paper of Dandeno (American Journal of Science, Vol. XVII, June, 1904) in this field is especially interesting, but a direct comparison of results in toxic salt solutions can not be made, owing to the fact that seedlings of different plants have been used.

Lupinus albus. Although the order of toxicity of the various salts remained the same in the three series of experiments, quite different limits of endurance were obtained, those in the first series made by the writer being much higher than those obtained by Kearney and Cameron and by the writer in his second series. The idea was at once suggested by these results that while possibly the second lot of seed may have differed only in being younger or otherwise more vigorous it was also possible that different varieties or even merely strains from different sources of the same species might differ considerably in their power to resist toxic salt solutions. It was therefore with a view of determining whether or not this was true that the series of experiments which forms the subject of this paper was undertaken with different varieties of wheat.

Attention should be directed at the outset to an important condition under which this work was carried on. Most of the work of this kind has been conducted with comparatively few seedlings. But individual variation in resistance is well known to be exceedingly great, and enough seedlings must be tested to eliminate all such differences. The average of the resistances of a large number of seedlings must be ascertained. The writer has in every case used from 50 to 100 seedlings, and more in some cases, the number tested being considered sufficiently large to eliminate individual variation and give fairly consistent results. The total number of seeds experimented with aggregated nearly 5,000.

The work, the results of which are shown in this paper, was taken up at the suggestion of Mr. Thomas H. Kearney, Physiologist, of the Laboratory of Plant Breeding of the Department of Agriculture.

SALTS USED.

It was decided to employ the same salts used by Kearney and Cameron in their work with *Lupinus albus*, i. e., sodium chlorid ($NaCl$), sodium sulphate (Na_2SO_4), sodium carbonate (Na_2CO_3), sodium bicarbonate ($NaHCO_3$), magnesium sulphate ($MgSO_4$), and magnesium chlorid ($MgCl_2$). A basis for direct comparison is thus obtained. It was thought best to use these salts, also, because of their common occurrence in saline soils, and their tendency, in a greater or less degree, to inhibit vegetable growth.

VARIETIES SELECTED.

The selection of the varieties of wheat to be used in this work has not been an easy matter, there being a number of details to consider in making the choice. To prove whether there is a difference in the power of different varieties of the same species to resist the action of toxic salt solutions it was decided to use varieties representing very

different conditions of climate and soil, and selections were made, with the aid of Mr. M. A. Carleton, Cerealist of the Bureau of Plant Industry, with this end in view. All conditions under which wheat is grown are not, of course, represented. Wheat is raised in nearly every portion of the temperate zone and under as diverse conditions of soil and climate as could well be imagined. An attempt has been made, however, to obtain varieties representative of the regions presenting the greatest contrast in these respects. Cerealists have discovered that wheats well adapted to a humid region will not thrive in an arid or semiarid region, nor will varieties that are best adapted to the latter conditions thrive in a humid environment. Varieties representing each of these different climatic types were used in the experiments. Unquestionably the soils of the various regions from which the seeds were obtained differed chemically to a great extent, but in most cases data as to soil composition were not obtainable. The influence of climatic and soil factors is complicated by the fact that seeds are often transferred from one region to another. For example, a certain variety might have been grown for a number of years in strongly saline soil to which it has become thoroughly adapted, and then transferred to a semiarid region and a soil containing less salt. Were the seed procured from the new region soon after the transfer, while the variety was not yet adapted to the new conditions, probably it would still show the high degree of resistance acquired under the former conditions. In some cases it was possible to learn the exact history, for several generations, of the seed used, but in others it was impossible to obtain such definite information. To meet the conditions of the experiments it was thought advisable to select varieties from regions widely separated geographically. Therefore, one variety from Africa, two from Europe, one from Asia, and six from America were obtained. Two of the varieties are durum wheats and consequently of a different species; the rest are soft grained.

The following descriptions of the individual varieties will render more intelligible the conditions under which they grew originally:

PRESTON.

The variety of wheat known as Preston (*Triticum vulgare*) is a hybrid, produced by Dr. William Saunders, of the agricultural experiment station at Ottawa, Canada. In the spring of 1888 Doctor Saunders crossed the varieties Red Fife and Ladoga, obtaining a new sort, which was called Preston. Red Fife was taken as the male and Ladoga as the female parent. The progeny, he says, resembles somewhat both parents. The grain is very much like Red Fife. Both the parent varieties are well established in that part of Canada and were

grown there with great success for many years previous to the origin of this hybrid. Preston has proved to be a better variety than either of its parents, both in yield and in range of adaptability. The region in which its parent varieties grow is very humid. Doctor Saunders claims that Preston ripens its grain from three to four days earlier than either of its parents. In view of this fact it is reasonable to conclude that it is better adapted to regions having diminished rainfall during the latter part of the season, and experience has justified the conclusion. Preston has given the best results of all the spring wheats introduced into the Northwest. It is to-day grown successfully in the southern part of Canada and in a part of the United States that includes North Dakota, eastern Montana, Minnesota, South Dakota, and Wisconsin.[a]

TURKEY.

Turkey wheat (*Triticum vulgare*) is considered the hardiest variety grown at the present time in the United States. It is a bearded sort, with white chaff, small head, and red grain. It is especially well adapted to semiarid regions, as is readily seen from the region in which it is grown. This variety was introduced into Kansas about twenty-five years ago. For a while it was confined to a small district of that State, but during the past twelve or fifteen years its excellent quality has become generally known, and consequently it is grown on a much larger area. It came originally from Crimea and other portions of Taurida, in southern Russia. That country does not differ greatly from the section of the United States in which the variety has given such good results. Though it is not a variety giving unusually heavy yields, it is well adapted to resist droughts and may be depended upon for a greater average yield than any other variety grown in Kansas. It ripens rather early, and thus escapes the excessive droughts which frequently prevail during the latter part of the wheat season in that district. It is especially adapted to the Great Plains region, including, roughly, Kansas, Oklahoma, southern Nebraska, southern Iowa, northern Texas, and portions of Missouri and Arkansas.[b]

ZIMMERMAN.

The variety known as Zimmerman (*Triticum vulgare*) is grown to some extent in the same region as the one just described. However, it has a number of essential points of difference and some char-

[a] Dr. William Saunders, Cereals and Root Crops, Ottawa, Canada, 1902.

[b] Carleton, M. A., Basis for the Improvement of American Wheats. Bul. 24, Division of Vegetable Physiology and Pathology, U. S. Department of Agriculture, 1900.

acteristics that make it preferable for the experiments described here. As a whole, it is inferior to the Turkey wheat, being less resistant to drought, and it is grown principally in regions which have a greater annual rainfall. Zimmerman wheat has two good qualities to recommend it—it is beardless and ripens from four days to a week earlier than other varieties in the same locality. It is a fairly hardy sort, and is as resistant as the average variety to the cold of severe winters. It is best adapted for cultivation in southern Kansas, Oklahoma, northern Texas, Missouri, Kentucky, Tennessee, Arkansas, and farther southward. This region has a much larger annual rainfall than the one inhabited by the Turkey variety, with the exception of the States in common—Kansas, Oklahoma, and Texas.

KHARKOF.

The seed used of the Kharkof variety of wheat (*Triticum vulgare*) was obtained by the United States Department of Agriculture from the Agricultural Society of Kharkof, Russia, in the Starobielsk district. Kharkof is in the southern part of Russia, about 300 miles north of the Black Sea and about 350 miles west of the Volga River. The winters are very dry and at no season of the year is the rainfall great. Kharkof is a red-bearded, hardy winter wheat. The seed was obtained from the crop grown in Russia during the season of 1902.

PADUI.

Seed of the Padui variety (*Triticum vulgare*) was obtained from Saratof, in eastern Russia. Saratof is located on the Volga River, about 400 miles from its outlet into the Caspian Sea. Padui is a soft or semihard winter wheat, and is adapted to all northern winter-wheat States from New York to Kansas and southward to the thirty-fifth parallel. The seed with which these tests have been made was imported directly from Russia. Padui is very resistant to drought, the rainfall in the region where it is grown falling as low as 12 to 15 inches per annum. This variety is cultivated to some extent in the same region as Kubanka (described later), and, therefore, is subjected to the same climate and probably to the same soil conditions.

CHUL.

Dr. E. A. Bessey describes the conditions under which the Chul variety (*Triticum vulgare*) is grown in Turkestan and in the southern part of central Asia, about Samarkand. It is found more or less in this whole steppe region, from which it derives its name, Chul meaning steppes. It is a hard grain and grows without irrigation, yields two harvests, and can be sown as either winter or

spring wheat. The seed for these experiments was obtained by Doctor Bessey for the Department of Agriculture from its native country, being taken from the crop of 1902.

BUDAPEST.

The variety known as Budapest (*Triticum vulgare*) is one of the hard winter wheats imported originally from Hungary. It is now grown in Michigan and adjoining States with great success. Of all the varieties imported from Hungary, Budapest has proved the best. It is well suited for cultivation in the North Central States, including Michigan, Illinois, Indiana, Ohio, western New York, Kentucky, and perhaps farther south. It is a bearded wheat, with white chaff and red, medium hard grain. It is a success only in regions with a fairly large rainfall.

KUBANKA.

The two varieties of durum wheat (*Triticum durum*), Kubanka and Maraouani, were selected outside of the species *vulgare* in order to find types grown under extremely arid conditions. The seed of Kubanka was obtained originally from Russia. The seed used was of the fourth generation grown in the United States and should show something of the effect of soil and climatic conditions here, provided these differ essentially from those of the country where it originated. Four years is doubtless sufficient time to acclimatize the variety fairly well. Kubanka is grown in an extensive area of eastern Europe and western Asia, especially along the Volga River. The best Kubanka is found east of the Volga, on the border of the Kirghiz Steppe. It is about the only variety found along the Siberian border, where it is impossible to grow any ordinary sort because of drought, and is grown extensively by the Turgai and Kirghiz people. The rainfall over this whole region often does not exceed 10 inches per annum. The Kubanka variety matures very quickly, an absolute necessity in a region where the rainfall is very slight and often confined to a small part of the year. Because it is drought-resistant and matures early it is now being grown throughout the Volga territory from Kazan to the Caspian Sea and east to the Kirghiz Steppe and Turkestan. It is a macaroni wheat, and takes its name from Kuban territory. In this country it is best adapted for the northern plains region as far south as Kansas.

There is little doubt that the varieties Kubanka and Padui, in some regions at least, grow on soil containing considerable salt. Both varieties have become well adapted to the region just north of the Caspian Sea along the Volga River. Here salt abounds in great quantities. West of the Volga and about 100 miles from the Caspian

Sea is a great salt marsh covering a considerable area. On the other side of the river, for a couple of hundred miles along its course, there are both salt marshes and lakes. The great Khaki salt marsh along the borders of the Kirghiz Steppe covers several hundred square miles. Northward and westward from this marsh there is a series of small salt lakes, the largest of which is Elton Salt Lake. It would naturally be expected that in a region with such extensive salt marshes and lakes the arable soil would likewise contain a large proportion of salt.

MARAOUANI.

The Maraouani variety of durum winter wheat (*Triticum durum*) has been grown in northern Africa probably for centuries. As far as can be ascertained, it originated there and has long been one of the most valuable sorts of that country. The seed used in these experiments came directly from the Chéliff Valley, an arid region with very little rainfall, in the western part of Algeria. The wheat land there is cultivated for the most part without irrigation. The soil is largely a heavy clay loam, and probably contains in nearly all sections a more or less excessive amount of readily soluble salts. Maraouani is very hardy, is resistant to rusts, and has the reputation of being the best of the durum wheats now grown in that region. In the Department of Oran it is most successful when sown in November; it then matures about June. It is thought by expert cerealists that this variety would succeed well in the spring-wheat regions of the northern United States and as a winter wheat in the Southwest.

METHODS OF EXPERIMENTS.

Wheat seeds are small compared with lupines, beans, peas, etc., with which most of the work of other experimenters has been done. The rootlets of the wheat seedlings are so small that at first it was feared that some difficulty would be experienced in marking off the rapidly growing zone with india ink, the readiest method for accurate determination of the death point. In view of this difficulty the work was begun without marking. It required but a few trials, however, to prove that it would be practically impossible to obtain satisfactory results in such a way. Wheat rootlets have a hard surface and do not become flaccid in salt solutions unless these are of a concentration much beyond the toxic limit, in which case the roots become yellow and the cells somewhat broken down. However, one or two attempts at marking showed that with a little practice and care this could be effected without inflicting any injury. By rupturing the epidermis very slightly a sufficiently conspicuous mark, which will last forty-eight to seventy-two hours, can be made without injury to the roots.

The seeds were put in sphagnum moss finely broken up and kept sufficiently moist to preclude lateral branching or superfluous development of root hairs. They germinate readily in about forty-eight to seventy-two hours at an ordinary room temperature. The rootlets and leaves make their appearance almost at the same time. The number of roots varies with the variety, but is usually from three to seven. Three is the average number, five is rather common, and seven not very rare. Only one root of each seedling was marked. The initial or central one was always preferred when otherwise fit for the purpose. However, it was found after a large number of tests that the central one was most likely to become deformed while in the sphagnum moss, the tips becoming enlarged and blunt, in which case the root soon ceases to grow. When this happened side roots were preferred for marking. Rootlets which are smooth and uniform in thickness, with a rather sharp point, are most vigorous and give best results. Only experience in this work can teach one which of several roots is preferable for marking. The seeds were taken from the moss, marked, and transferred quickly to the solution. Care was taken in every way possible to avoid change of conditions during the process of making. These details will be discussed more fully in another part of this paper.

The solutions during the period of experiment were kept in the best nonsoluble beakers that could be obtained, each being large enough to hold about 300 c. c. After the solutions had been used once or twice [a] the glassware was thoroughly rinsed in distilled water before being used for the next test. Nearly every other day the beakers were thoroughly sterilized by boiling in distilled water. The beaker used is about 6½ cm. wide at the mouth, and was closed by a tight-fitting cork about 1 cm. in thickness. Each cork was perforated, and into the holes five small glass rods were inserted, bent at one end, and drawn to a sharp point. The rods were inserted with their hooked points on the inner side of the cork, and upon each a single seed was placed. The rods, as well as the corks, fit tightly and thus prevent any important amount of evaporation from the solution. They are free enough, however, to permit of the rods being raised or lowered in or out of the solution as occasion may demand. In no case were the glass rods allowed to come in contact with the solution.

Normal solutions, made with Merck's best chemically pure salts, were prepared under the supervision of Dr. F. K. Cameron, of the Bureau of Soils of the Department of Agriculture. From the nor-

[a] Careful titration showed no appreciable change in the concentration of the solution after several seedlings had been kept in it for twenty-four hours, or even when the same volume was used during a second period of twenty-four hours.

mal solutions stock solutions were made up by dilution, and were kept for use as required. The solutions actually used in the experiments were made from the stock solutions by diluting with distilled water. It might seem at first that two successive dilutions would permit of an error. This, however, has been avoided in the case of chlorids and carbonates by titrating each stock solution before using. The concentration of the solutions of sulphates was frequently verified by analysis in the Bureau of Soils. Sodium carbonate and sodium bicarbonate were both titrated against N/20 hydrogen potassium sulphate, using methyl orange as an indicator. In the case of the bicarbonate solutions it was necessary to charge them with an excess of carbon dioxid to prevent their becoming alkaline. The nonalkalinity of the bicarbonate solutions was often tested by the addition of a drop of alcoholic phenolphthalein, which would indicate the presence of alkalis by forming the well-known red color. Sodium chlorid and magnesium chlorid were titrated against N/10 of silver nitrate. Whenever, upon titration, any stock solution was found to be either too dilute or too concentrated, it was corrected by the addition of more of the normal solution or by further dilution with distilled water. The water used in these experiments was distilled in the Laboratory of Plant Pathology, and near the close of the work was found by analysis in the Bureau of Chemistry to contain some slight amount of a toxic substance. That this was for all practical purposes neutralized and played no part in the toxic action of the solutions used is demonstrated in the fuller discussion of this point on page 39 of this paper.

All seeds for these experiments were germinated in sphagnum moss. After being finely broken up the moss was placed in a bucket and kept sufficiently moist for seed germination. It was found that the seedlings were injured if kept too moist, the roots showing an enlargement at the apex, developing into a very blunt tip, and when affected in this way they usually stopped growing and new roots were put forth. The initial radicle was more easily affected in this way. Only seedlings having healthy and vigorous rootlets were used in the experiments. The seeds were first soaked in hydrant water from four to six hours before being placed in the sphagnum moss. After about three days in the temperature of an ordinary room they were ready for use. They were most easily manipulated when the radicles were from three to four centimeters long. The root itself might well be longer, but the apical bud appears almost at the same time as the root, and when more than one or two centimeters long interferes with easy adjustment in the beakers. It was sometimes necessary to pinch off the ends of the leaves, a practice which in no way interfered with the development of the rootlets. When the radicles had reached the length mentioned above, the seedlings were taken out of the sphag-

num and placed in beakers containing the solution, the tips of the roots being immersed in the liquid. One rootlet of each seedling was marked with india ink 15 mm. from the apex, which should include practically all of the rapidly growing zone. The amount of elongation during a given period could thus be determined, and this is the best means of knowing whether the root has been actually killed. Unless the concentration of the solution be far above the toxic limit the root does not become flaccid, as is the case with lupines and some other seedlings. After the roots were marked with india ink the seeds were carefully hooked on to the glass rods prepared for that purpose. As much of the root was immersed in the solution as was possible without allowing the seeds or rods to come in contact with the liquid. In all cases the entire length of the marked zone was immersed. The length of the portion of the root in the solution depended, of course, upon the total length of the root. It might at first glance seem that a variation in this respect could affect the result of the experiment, some roots having a larger surface exposed to the solution than others; but it is believed that the large number of seedlings used in each experiment practically eliminated this source of error.

All cultures were left in the solution twenty-four hours, when they were taken up and the amount of elongation of the marked portion of the root was measured and recorded. They were then transferred to a beaker containing hydrant water and allowed to remain there for another twenty-four hours, when they were taken up and the elongation again measured. The radicles which made an additional growth the second twenty-four hours in the hydrant water over the growth in the first twenty-four hours in the salt solution were considered to have survived in the solution and were thus recorded. Those making no additional growth the second twenty-four hours were considered dead and recorded in this way. Coupin and others have intimated that twenty-four hours is not sufficient to kill the plant. This objection is set aside by the consideration that only the death of the apex of the root is regarded in these experiments and not the point at which the whole plant succumbs. The object of this work is merely one of comparison of the effect of a solution of given concentration, during a definite period of time, upon different varieties. Whether this effect is expressed in the death of the whole plant or only that of a single organ is immaterial.

Control experiments were carried on every day, one in hydrant water and one in distilled water, both under conditions identical with those in the salt solutions. The results in hydrant water have been uniform from day to day and in only a few cases were they proved unsatisfactory. In such cases the whole series was discarded, the inference being that some unfavorable condition (of temperature, for example) had interfered.

A word as to the conditions of illumination and temperature during the experiments will not be out of place at this point. When in solutions the roots were exposed to the light during the day. When in the salt solutions during the first 24 hours they were kept on a shelf in the rear of a room with northern exposure only. When in hydrant water during the second 24 hours they were kept on a table at the window, under a moderately strong light. Preliminary experiments were made when commencing the work with lupines, which showed that the strength of the light, at least within the limits involved in these experiments, had no influence on the growth of the roots. Of three series of cultures, all in a solution of the same salt at the same concentration, one was placed in total darkness, another in subdued light, and a third in bright light. Otherwise they were under the same conditions. The elongation of the roots was measured at the end of 24 hours and there was no appreciable difference in the three sets of cultures.

It was impossible to keep a uniform temperature in the laboratory during the winter months, though this factor did not vary enough in either direction to cause any injury in germination or to the roots in the solution. A thermograph was kept running in the room, and a review of the records shows no temperature below 18° or above 30° C. The average temperature during the experiments was about 23° C. When making the experiments with illumination referred to above, similar ones were made to determine the influence of temperature upon the roots. The three different series of cultures (all in the same salt solution, at the same concentration) were exposed for 24 hours to temperatures of 10°, 20°, and 30° C., respectively. Results showed that the roots that had been exposed to a temperature of 20° and 30° C. showed about the same elongation, while the elongation in a temperature of 10° C. was somewhat less.

All solutions were made with water distilled from ordinary hydrant water. The receiver of the still is a porcelain tub and has been used for several years in the Laboratory of Plant Pathology of the Bureau of Plant Industry. At times the distilled water may have contained some slight traces of ammonia and doubtless some other impurities. An analysis of the water was made in the Bureau of Chemistry, and it was found to contain, in parts per million—

Zinc	Trace.
Free ammonia	0.125
Albuminoids	.014
Nitrates	None.
Nitrites	Faint traces.
Total solids (consisting of calcium, sodium, carbonates, sulphates, and chlorids)	7.4

A further discussion of the water used will be found on page 39.

METHOD OF ESTABLISHING THE TOXIC LIMITS.

Before going into details of the results obtained in the simple solutions, the methods of determining the limits of endurance of each variety to each salt will be explained. At one time the writer had thought of fixing the limit of endurance in toxic salt solutions at the concentration in which none of the marked radicles would survive at the end of twenty-four hours. A few experiments, however, showed that this was not the proper method, for occasionally one of the rootlets would be sound and healthy at the end of twenty-four hours in a concentration far above that which would permit the roots of a majority of the plants to survive. In other words, individual variation plays such an important part that the strength of a solution which would permit no root tips to survive would be far above that representing the limit of endurance for the variety as a whole. Attention is thus once more directed to the fact that results obtained from a few individuals are as a rule very inaccurate and unreliable. The characters of a variety (and resistance to toxic effects is one of its characters) are the mean of those of the whole number of individuals composing it. Of course all the individuals of a variety can not be examined, but the number of seedlings experimented with should be large enough to overcome the effect of marked individual variation. It was this consideration that urged the writer to make such a large number of tests. On the other hand, a concentration which would just permit all root tips to survive would not represent the general limit for the variety because of those few individuals which are far inferior to the average in their ability to resist toxic salt solutions. The limit of endurance for the mean of the largest possible number of individuals is the end sought.

After consideration, it seemed that the most perfect idea of the limit for each variety could be obtained by taking the concentration in which about half the seeds survived and about half died. For instance, if 60 seeds were tested in a 0.01 normal solution of magnesium sulphate and 30 survived and 30 died, the toxic limit would be represented by that concentration. Of course it was seldom possible to secure such an equal division, but a slight excess one way or the other would not materially alter the results. In practice it was, furthermore, often found expedient to take the mean of the concentrations actually tested as representing the toxic limit.

To illustrate: The roots were often found dead in a 0.01 normal solution of magnesium chlorid, and alive in a 0.0075 normal. The approximate toxic limit was fixed at the concentration intermediate between these two, although no solutions intermediate in concentration between 0.01 and 0.0075 of a normal solution were actually made up.

The writer does not claim that the limits thus fixed are absolute, but he believes that further experiments would change them very little. To obtain absolutely exact results it would be necessary to employ an indefinite number of solutions of intermediate concentration, and to make tests with a very large number of seedlings. The results recorded here, it is safe to assume, will answer all practical purposes. The different strengths of solution of the same salt differed from each other by 0.005 of a normal solution for sodium chlorid, sodium sulphate, and sodium bicarbonate, and by 0.0025 of a normal solution for sodium carbonate, magnesium sulphate, and magnesium chlorid. That is to say, experiments were made with solutions of a concentration of 0.015, 0.01, 0.005, etc., for sodium chlorid, sodium sulphate, and sodium bicarbonate, and of a concentration of 0.01, 0.0075, 0.0025, etc., for magnesium chlorid, magnesium sulphate, and sodium carbonate, intermediate concentrations being disregarded in practice.

As mentioned earlier in this paper, the death point was determined largely by the elongation of the roots beyond the point 15 mm. from the tip, marked off by india ink. If the roots showed no additional elongation the second 24 hours in hydrant water, they were considered dead. In some cases, however, it has been possible to determine this point by other means.

In the case of the two magnesium salts a solution of a concentration considerably above the limit blackens about 1 or 2 millimeters of the root tip, and often causes the end of the root to bend in the shape of a hook. An appearance of this kind is conclusive evidence that the solution is much too concentrated. Both sodium carbonate and sodium bicarbonate in very strong solution cause a yellowing of the whole body of the root in the solution, and more or less loss of turgor, due, doubtless, to plasmolysis. It is very seldom that rootlets which show that condition at the end of twenty-four hours in the solution will revive when placed in hydrant water.

To make the results herein contained exactly comparable with those furnished by Kearney and Cameron from their studies on lupines, the toxic limits are given in this paper both in fractions of a normal solution and in parts of salt per 100,000 of solution. In addition, the mean of the limits of all the varieties is given under each salt, so that a glance will show how much above or below this point any particular variety may be in regard to each salt used.

The salts have been found harmful in pure solutions in about the order in which they follow each other in the succeeding part of this report—that is, sodium sulphate is less harmful than sodium chlorid when both are in equivalent concentration, and magnesium sulphate is more harmful than sodium bicarbonate when in the same pro-

portion. A concentration of 0.0075 normal magnesium sulphate usually produces about the same effect as 0.025 sodium bicarbonate. Therefore one would say that magnesium sulphate is three times as injurious as sodium bicarbonate when in equivalent concentration.

RESULTS OF EXPERIMENTS.

RESULTS WITH MAGNESIUM SULPHATE.

The results obtained for the different varieties with pure solutions of magnesium sulphate are shown by the following table:

Name of wheat variety.	Maximum limit of endurance.	
	Parts per 100,000 of solution.	Fractional part of a normal solution.
Zimmerman	42	0.0075
Kharkof	25	.00625
Padui	42	.0075
Kubanka	42	.0075
Turkey	56	.01
Maraouani	42	.0075
Budapest	56	.01
Preston	28	.005
Chul	28	.005
Average for all varieties	40	.00736

A glance at the above table is sufficient to show the considerable difference between the varieties in their ability to resist the toxic influence of magnesium sulphate. The least resistant of all the varieties are Chul and Preston, of which about half the seedlings survived in a 0.005 normal solution. Contrasted to these are the two most resistant ones, viz, Budapest and Turkey, surviving equally well in a solution twice as concentrated.

A comparison of these results with wheat with those obtained by Kearney and Cameron using *Lupinus albus* with the same salt will show the great diversity between these two plants. The toxic limit for lupines in a pure solution was found to be 0.00125 of a normal solution. Accepting the results shown by these figures, magnesium sulphate is four times as toxic to lupines as it is to the Chul and Preston wheats, and eight times as toxic as for the Budapest and Turkey varieties. It may be said in this connection that from experiments made by Kearney[a] with maize there is reason to believe that the Gramineæ as a family are much less sensitive to the effect of magnesium salts than the Leguminosæ. Magnesium sulphate has been found in the course of these experiments with wheat to be on an

[a] Science, N. S., 17: 386 (1903).

average much the most toxic of the salts used. It was the most injurious in every case except in two instances, in one of which sodium carbonate and in the other magnesium chlorid proved more toxic. It required a solution of magnesium sulphate twice as concentrated as that of sodium carbonate to be equally toxic to the Budapest variety, the limits in this case being 0.01 normal magnesium sulphate and 0.005 normal sodium carbonate. The other instance referred to is not so marked. Magnesium chlorid is found to be somewhat more toxic than magnesium sulphate for one variety—Turkey—the limits being for magnesium chlorid 0.0075 normal and for magnesium sulphate 0.01 normal.

Comparing the average toxic limit for each salt, as stated in the tables that follow, magnesium sulphate is one and two-sevenths times as injurious as magnesium chlorid, one and three-sevenths times as injurious as sodium carbonate, three and five-sevenths times as injurious as sodium bicarbonate, little more than six times as toxic as sodium sulphate, and seven and five-sevenths times as injurious as sodium chlorid.

Magnesium sulphate in the soil is not considered injurious to any appreciable extent, but this is no doubt due to the neutralizing effect of other salts with which it is associated. Kearney and Cameron, in their experiments on *Lupinus albus* and *Medicago sativa*, found magnesium sulphate in pure solutions to be the most toxic of all the salts. The writer found the same true for the lupines. But when other salts are added to a solution of magnesium sulphate, toxicity, both absolute and relative, is altered. Kearney and Cameron [a] say:

> Addition of sodium sulphate, which itself is injurious in pure solution, raises the limit of magnesium sulphate three times, while the presence of calcium sulphate allows a small proportion of the roots to barely survive during twenty-four hours in a solution of magnesium sulphate 480 times as concentrated as that which in pure solutions represents the limits of endurance.

To lower classes of plant life magnesium sulphate is apparently much less toxic. Dr. B. M. Duggar [b] has made some experiments with marine algæ to determine the nutrient value of the salts of some of the alkalis and alkali earths when added to sea water. He found that after the acids and some of the salts of the heavy metals the potassium phosphates proved most toxic. The least toxic were the salts of sodium and magnesium, while the sulphate of magnesium was the least injurious of all the salts used. The less injurious effect

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[a] Some Mutual Relations Between Alkali Soils and Vegetation. Report No. 71, U. S. Department of Agriculture (1902).

[b] The Toxic Effect of Some Nutrient Salts on Certain Marine Algæ. Science, N. S., 17: 459 (1903).

of the magnesium salts is probably due to the presence of neutralizing salts in the sea water to which he added the magnesium compounds, although we are not yet in a position to say that magnesium may not be far less toxic to the Algæ than to the Leguminosæ or Gramineæ.

To show the relative toxic effect of magnesium sulphate to some of the other salts, Loew [a] has made some interesting observations, and states that Spirogyra died within four or five days in a 1-per-mille solution of magnesium sulphate, but remained alive for a long time in corresponding solutions of the sulphates of sodium, potassium, and calcium. Upon the roots of some higher plants the same investigator made similar observations, and says that Vicia and Pisum do not start lateral roots when kept in a solution of 0.5 per cent of magnesium sulphate or nitrate, and the root cap and epidermal cells die after a few days. Seedlings of Phaseolus placed in a solution of 0.1 per cent magnesium sulphate with 0.1 per cent of monopotassium phosphate showed injury to the roots after five days, and the entire plant succumbed soon afterwards.

Coupin [b] found during the course of some experiments with wheat that magnesium chlorid was more toxic than magnesium sulphate. He gives the limit for magnesium sulphate at 1 per cent and for magnesium chlorid at 0.8 per cent.

RESULTS WITH MAGNESIUM CHLORID.

The following table shows the results obtained for the different varieties with pure solutions of magnesium chlorid:

Name of wheat variety.	Maximum limit of endurance.	
	Parts per 100,000 of solution.	Fractional part of a normal solution.
Zimmerman	72	0.015
Kharkof	48	.01
Padui	48	.01
Kubanka	42	.00875
Turkey	36	.0075
Maraonani	48	.01
Budapest	60	.0125
Preston	24	.005
Chul	24	.005
Average for all varieties	40	.00931

[a] The Physiological Rôle of Mineral Nutrients in Plants. Bul. 45, Bureau of Plant Industry, U. S. Department of Agriculture (1903).

[b] Sur la Toxicité du Chlorure de Sodium et de l'Eau de Mer a l'Egard des Végétaux. Revue Générale de Botanique, 10: 188 (1898).

Magnesium chlorid, like the sulphate, seldom occurs alone in nature in sufficient quantity to be of very great consequence. It is nearly, if not always, associated in the soil with some other salts, such as those of sodium and calcium, which tend to neutralize its effect upon plants. In these experiments with wheat, as in those with lupines, it was found to rank next to magnesium sulphate as a toxic agent when in pure solutions.

The average limit of concentration of magnesium chlorid for wheat seedlings is 0.00931 of a normal solution, as against 0.00736 for magnesium sulphate. Again, referring to Kearney and Cameron's results with the same salts for lupines, we find some variations. As is easily seen with the writer's results with wheat, magnesium sulphate is only about one-third more toxic than magnesium chlorid, while Kearney and Cameron's results show the sulphate twice as toxic as the chlorid. The investigators named found the roots of lupines to barely survive in 0.0025 of a normal solution of magnesium chlorid, while Kearney showed that *Zea mays* would live in a solution a little more than thirty times as concentrated. Magnesium chlorid is twice as toxic to the white lupine as to the least resistant variety of wheat tested, and six times as toxic to the lupine as to the most resistant variety of wheat. It is a surprising fact that some varieties of wheat are six times as resistant and that maize is thirty times as resistant to this salt as *Lupinus albus*.

It will be seen that the variation of the wheat varieties among themselves is more pronounced in the chlorid than in the sulphate. While the toxic limit for the least resistant of the varieties is the same (0.005 of a normal solution) for the two salts, that of the most resistant variety (0.015 normal) is much higher in magnesium chlorid than in the sulphate. The ratio of variation between the two extremes of resistance with magnesium sulphate was 2 to 1, as against 3 to 1 with the chlorid.

RESULTS WITH SODIUM CARBONATE.

The following table gives the results with pure solutions of sodium carbonate:

Name of wheat variety.	Maximum limit of endurance.	
	Parts per 100,000 of solution.	Fractional part of a normal solution.
Zimmerman	65	0.0125
Kharkof	78	.015
Padui	52	.01
Kubanka	39	.0075
Turkey	78	.015
Maraouani	41	.008
Budapest	26	.005
Preston	65	.0125
Chul	65	.0125
Average for all varieties	57	.0109

The results shown by the above table are not materially different from those with magnesium chlorid. Sodium carbonate in pure solutions is slightly less harmful, as shown by the comparison of the average of all the varieties, being in the case of magnesium chlorid 0.0093 and for sodium carbonate 0.0109 of a normal solution. The extremes in both cases are the same, though there are two varieties with a resistance of 0.015 for sodium carbonate as against one for magnesium chlorid. Five varieties in the case of sodium carbonate have a resistance above the average as against four in the case of magnesium chlorid. One variety alone, Budapest, has a resistance of only 0.005 as against two for magnesium chlorid.

Of the three salts so far described, sodium carbonate is in the soil generally the most harmful, (1) because in excessive quantity it is more widely distributed, and (2) because it is less easily neutralized by other salts with which it is usually associated.

The opinions of experimenters differ considerably as to the relative toxic effect of this salt. Kearney and Cameron showed that, in the case of *Lupinus albus* at least, sodium carbonate is but little more injurious than sodium sulphate, the toxic limit in each case being 0.005 and 0.0075 of a normal solution, respectively. It will be seen that the limit for the lupine obtained by them with sodium carbonate is the same as the resistance for Budapest wheat, but only one-third of that for the Turkey and Kharkof varieties. The limit of concentration for the lupine, as shown by their report, is about equivalent to one-half of the average for the several wheat varieties, in the same salt solution. Kearney found *Zea mays* to survive in the same salt at a concentration three times as great as that repre-

senting the limit for the lupine, and equal to that for the most resistant varieties of wheat.

Coupin [a] found the toxic limit of wheat in sodium carbonate to be about 1.1 per cent. In view of the fact, however, that he noted the death of the whole plant and not the root tips, the limit of concentration as determined by him would necessarily be much higher.

RESULTS WITH SODIUM BICARBONATE.

The limits in pure solutions of sodium bicarbonate are shown in the following table:

Name of wheat variety.	Maximum limit of endurance.	
	Parts per 100,000 of solution.	Fractional parts of a normal solution.
Zimmerman	234	0.028
Kharkof	251	.03
Padui	230	.0275
Kubanka	209	.025
Turkey	230	.0275
Maraouani	188	.0225
Budapest	209	.025
Preston	209	.025
Chul	209	.025
Average for all varieties	219	.026

Of all the salts used sodium bicarbonate seems to bring out the least variation in resistance so far as these experiments are concerned. The least resistant variety was Maraouani and the most resistant Kharkof, which were able to survive in a 0.0225 and 0.03 normal solution, respectively. These results do not differ to an important extent from those of Kearney and Cameron for *Lupinus albus*, the toxic limit of which was slightly lower (0.02) than that for Maraouani wheat.

The writer finds sodium carbonate to be about two and six-tenths times as injurious to wheat when in equivalent concentration as sodium bicarbonate. Kearney found the difference to be even greater in the case of maize, the ratio being about 4 to 1. Coupin [b] reverses the relative toxic order of these two salts. This difference in the

[a] Sur la Toxicité du Chlorure de Sodium et de l'Eau de Mer a l'Egard des Végétaux. Revue Générale de Botanique, 10: 180 (1898).

[b] Sur la Toxicité des Composés de Potassium et de l'Ammonium a l'Egard des Végétaux Supérieurs. Revue Générale de Botanique, 12: 180 (1900).

criterion of toxic action, i. e., the death of the whole plant rather than of the root tip alone, should not affect the relative toxic influence of the two salts. Coupin's results showed that it required a 1.1 per cent solution of sodium carbonate to kill wheat seedlings, while only 0.6 per cent was necessary to produce the same effect when sodium bicarbonate was employed.

As to the relative toxic order of the carbonate and bicarbonate, the results recorded agree quite well with those of Sigmund,[a] who found that wheat development was retarded and germinating seeds of vetch and rape were killed in a 0.5 per cent solution of sodium carbonate, while the same concentration of sodium bicarbonate was quite harmless.

Kearney and Cameron found sodium bicarbonate somewhat less toxic than sodium chlorid for the lupine, and, further, that a 0.02 normal solution of sodium bicarbonate permits plants to survive in much better condition than in the corresponding concentration of the chlorid. Kearney has also shown by experiments that the bicarbonate is less toxic to maize than is sodium chlorid, the death point for the bicarbonate being established at 0.05 and for the chlorid at 0.04 of a normal solution.

In view of all these differences it will be no easy matter to decide the relative harmfulness of these sodium salts. Experiments will have to be performed on a large number of plants of widely different relationship before any definite conclusions can be reached. There is great probability that the order of their toxicity is not the same for all species of plants. This is very well demonstrated by a comparison of the writer's results with those of Kearney and Cameron, who found sodium sulphate more toxic to *Lupinus albus* than sodium bicarbonate, while the writer found the reverse to be true for wheat. There is a tendency among physiological experimenters to draw general conclusions for the whole plant kingdom from the results obtained for a few varieties, species, or genera, which is absolutely unjustifiable. Too much emphasis can not be used in condemning such inferences. The results here obtained, it is thought, will hold good for these particular varieties of wheat, but they are not indicative except within rather wide limits of what others show.[b] They

[a] Ueber die Einwirkung Chemischer Agentien auf die Keimung, Landw. Vers. Stat., 47: 2 (1896).

[b] This point is brought out in a most marked way by the work of Cameron and Breazeale upon the effect of acids on wheat, maize, and clover, respectively. (The Toxic Action of Acids and Salts on Seedlings, Journal Phys. Chem., vol. 8, No. 1, p. 1, Jan., 1904.)

will serve for making comparisons, but not for drawing conclusions as to the behavior of plants in general.

RESULTS WITH SODIUM SULPHATE.

The comparative effect of pure solutions of sodium sulphate upon the different varieties is shown in the table which follows:

Name of wheat variety.	Maximum limit of endurance.	
	Parts per 100,000 of solution.	Fractional parts of a normal solution.
Zimmerman	353	0.05
Kharkof	300	.0425
Padui	318	.045
Kubanka	353	.05
Turkey	300	.0425
Maraouani	336	.0475
Budapest	265	.0375
Preston	242	.035
Chul	283	.04
Average for all varieties	305	.0433

In sodium sulphate, as in sodium bicarbonate, the toxic limits for the different varieties show less variation than in the case of other salts used. The least resistant to this comparatively harmless salt, as to most of the others used in these experiments, is the Preston wheat. This variety has been grown for a number of years in a semihumid region where alkali soils do not occur. In view of these facts one would expect this variety to be somewhat less resistant to these salts. Since there is no excess of soluble salts in the soils of this region, Preston has had no opportunity to develop salt resistance. The varieties most resistant to sodium sulphate are Zimmerman and Kubanka, both surviving as well in a 0.05 normal solution as Preston in 0.035. As to the origin of these varieties, also, it is just what would be expected from their resistance to salts. Both sorts came from arid or semiarid regions, where saline soils are abundant. Kubanka is grown in regions containing numerous salt marshes and lakes, and that it should have acquired ability to resist salts in the soil is only natural. Zimmerman likewise was obtained from a region having soils of more or less saline character, and to this is probably due its power of resistance in salt solutions. It is not unlikely that the soils from the regions from which the remaining varieties were obtained contain a less amount of sodium sulphate

proportionate to their smaller resistance to this salt as shown in these water cultures. This can not definitely be known until experiments have been made correlating the amount of the different salts in the soil upon which the different varieties grew, with their resistance in pure solutions.

Some interesting differences can be noted here between the resistance of wheat and of lupines to sodium sulphate. The Preston variety is $4\frac{2}{3}$ times as resistant, and Zimmerman and Kubanka $6\frac{2}{3}$ times as resistant, as *Lupinus albus*, the toxic limit of the latter having been established by Kearney and Cameron at 0.0075. They found sodium sulphate more toxic to Lupinus than sodium bicarbonate, while for every variety of wheat in these experiments the reverse is true. With maize Kearney showed that the seedling would survive equally well in both salts, and established the limit at 0.05 of a normal solution.

Hilgard states that few plants can bear as much as 0.1 per cent in the soil of sodium carbonate, or about 3,500 pounds per acre to the depth of 1 foot. For sodium chlorid the limit in the soil is about 0.25 per cent. In the case of sodium sulphate, most plants can grow in the presence of 0.45 to 0.50 per cent in the soil. In view of this fact sodium chlorid under soil conditions would seem to be more toxic to most plants than the sulphate.

Stewart [a] has made a number of interesting tests on the power of seeds to germinate in the presence of sodium carbonate, sodium sulphate, and sodium chlorid. He found the carbonate and the chlorid to be more injurious than the sulphate. With one exception (rye seeds in the presence of the chlorid), 0.50 per cent of either carbonate or chlorid proved fatal to germination. Stewart showed that sodium sulphate is far less injurious than either of the other salts. The character of his experiments indicates, however, that they are not directly comparable with such as are here described. His seeds were placed for germination in sand on tin plates and watered, the nature of the water used not being stated. Kearney and Cameron have shown that these salts are decidedly different in the degree to which their toxic effect can be neutralized by the addition of other salts, such as the chlorid or sulphate of calcium. It is possible that the sand or the water, or both, used by Stewart contained more or less calcium salts. The results of Kearney and Cameron, above referred to, show that the toxic effect of sodium carbonate, and next to it that of sodium chlorid, are neutralized far less effectively by calcium sul-

[a] Effect of Alkali on Seed Germination. Ninth Annual Report, Utah Agricultural Experiment Station, p. 26 (1898).

phate than is sodium sulphate. They found that the resistance of sodium sulphate was raised 60 times by adding calcium sulphate. In the light of these facts it is easy to accept Stewart's results. In fact, Kearney and Cameron showed that when other salts were added the limit for *Lupinus albus* in sodium sulphate could be raised to 0.30 of a normal solution, and that for sodium chlorid only to 0.20, while in pure solutions the limit for sodium sulphate was a concentration of 0.0075 and for sodium chlorid 0.02. This also explains Hilgard's results as to the comparative harmlessness of sodium sulphate in the soil where other salts are always present.

RESULTS WITH SODIUM CHLORID.

The results obtained by the writer with pure solutions of sodium chlorid are shown in the following table:

Name of wheat variety.	Maximum limit of endurance.	
	Parts per 100,000 of solution.	Fractional part of a normal solution.
Zimmerman	377	0.065
Kharkof	319	.055
Padui	333	.0575
Kubanka	333	.0575
Turkey	290	.05
Maraouani	319	.055
Budapest	275	.0475
Preston	319	.055
Chul	261	.045
Average for all varieties	314	.0542

That sodium chlorid is the least toxic to wheat of all the salts used is evinced by the table above. Next to it, of course, is sodium sulphate. Comparing the results with those obtained by Kearney and Cameron for lupines, the varieties of wheat are two and one-half to three times as resistant. Coupin [a] also found wheat more resistant to sodium chlorid than the white lupines. He has experimented with several species of plants and found the whole plant to be killed in the following concentrations: Wheat, 1.8 per cent; peas, 1.2 per

[a] Sur la Toxicité du Chlorure Sodium et de l'Eau de Mer a l'Egard des Végétaux. Revue Générale de Botanique, 10: 178 (1898).

cent; vetch, 1.1 per cent; maize, 1.4 per cent, and white lupine, 1.2 per cent.[a]

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[a] Guthrie, F. B., and Holmes, R. (Roy. Soc. New South Wales, Oct. 8, 1902), conducted some experiments on wheats in two kinds of soils. To one of the soils was added a fertilizer consisting of a mixture of 15 grams of sulphate of ammonia, 6 grams of superphosphate, 4 grams of sulphate of potash, and varying quantities of other substances. The composition of the first soil was as follows:

	Per cent.
Moisture	3.83
Organic matter	13.75
Nitrogen	.208
Soluble in hydrochloric acid:	
Lime	.165
Potash	.065
Phosphoric acid	.107
Magnesia	.072

The soil was found to contain 0.016 per cent of sodium chlorid in addition to the substances enumerated above.

The composition of the second soil was as follows:

	Per cent.
Moisture	2.91
Organic matter	8.33
Nitrogen	.070
Soluble in hydrochloric acid:	
Lime	.440
Potash	.077
Phosphoric acid	.110

No fertilizer was added and the soil was originally free from chlorids. It was found that in the first soil the seeds germinated and grew well when enough sodium chlorid was added to the soil to give it a content of 0.066 per cent of that salt. Further, that in the second soil, to which no fertilizer was added, in the presence of 0.05 per cent of sodium chlorid, germination was slightly retarded, but the plants finally recovered and grew well. As to the results, these authors say:

From 0.01 to 0.02 per cent of sodium chlorid is without effect on the wheat plant, the grain germinating well and the plant growing vigorously. With 0.05 to 0.10 per cent of sodium chlorid the germination is somewhat retarded, the plants are less vigorous, but recover and grow well. With 0.15 the germination is still more affected and the plants would probably not recover under less favorable conditions than those of the experiment. Two-tenths per cent of sodium chlorid in the soil is fatal to the growth of wheat.

An experiment performed by Messrs. E. Charabot and A. Hébert (Compt. Rend. Acad. Sci. Paris, 134: 181, 1902), which shows the chemical influence of sodium chlorid upon more mature plants, is a very interesting one. These investigators found that by adding sodium chlorid some chemical properties are decreased.

The writer finds that a 2 per cent solution of sodium chlorid saturated with calcium sulphate is sufficient to kill moss growing on the soil in two weeks' time. At the end of one week no change is noticeable, except that growth is retarded. One week longer, however, suffices to kill the moss completely and turn it a brownish color. The solution was added to the pots on which the moss grew in the laboratory every other day for about that length of time.

SUMMARY OF TABLES.

In order to make more easily comparable the differences of resistance of the several varieties to the various salts, the results as a whole have been brought together in the following table. At the bottom of the columns is given the average, for each salt, of the toxic limits of all the varieties; so it requires only a glance to see which varieties are above or below the average in their resistance to the toxic effect of each salt.

Name of wheat variety.	Magnesium sulphate.	Magnesium chlorid.	Sodium carbonate.	Sodium bicarbonate.	Sodium sulphate.	Sodium chlorid.
Zimmerman	0.0075	0.015	0.0125	0.028	0.05	0.065
Kharkof	.00625	.01	.015	.03	.0425	.055
Padui	.0075	.01	.01	.0275	.045	.0575
Kubanka	.0075	.00875	.0075	.025	.05	.0575
Turkey	.01	.0075	.015	.0275	.0425	.05
Maraouani	.0075	.01	.008	.0225	.0475	.055
Budapest	.01	.0125	.005	.025	.0375	.0475
Preston	.005	.005	.0125	.025	.035	.055
Chul	.005	.005	.0125	.025	.04	.045
Average	.00736	.0093	.0109	.026	.0433	.0542

A glance at the above table shows that the Zimmerman variety is much the most resistant. This, however, does not necessarily mean that it is most resistant to every salt. On the contrary, Zimmerman is less resistant to magnesium sulphate than Budapest and Turkey, less resistant to sodium carbonate than Turkey and Kharkof, and less resistant to sodium bicarbonate than Kharkof. This same variety, however, is very resistant to the influence of sodium chlorid, sodium sulphate, and sodium carbonate, which brings up its average to a considerable extent. The least resistant variety is Chul, which runs low for all salts except sodium carbonate, in which its resistance is slightly above the average of the varieties with which experiments were made. The low resistance of this variety was unexpected, in view of the character of the country from which it came.

A further consideration of this table shows how nearly equal the Padui and Kubanka varieties are in their resistance. A comparison of the two varieties for the same salts shows but a slight variation. Taking into consideration the original habitat of the two varieties, we would expect very little difference. Both are Russian varieties and subjected to very similar climatic and soil conditions. Both varieties are very resistant to salt solutions, and in view of the fact that they both come from regions containing much saline soil their similarity in this respect is not surprising.

Good examples for contrast to Padui and Kubanka are furnished in Budapest and Preston. Budapest is a naturalized Michigan vari-

ety and Preston a variety from Canada. The soil and climatic conditions are very similar. Both regions are comparatively humid, with little or no saline soil. Both of these varieties are low in resistance to salt solutions, just as would be expected.

A comparison of the resistance of the different varieties with the region from which they came in respect to soil and climatic conditions shows that their resistance to saline solutions can probably be correlated with the natural habitat of the varieties; that is, the results herein obtained indicate that a variety grown in a locality having little or no excess of salts in the soil has a comparatively low resistance in saline water cultures. It further shows that varieties grown in regions having more saline soils have a much greater resistance in saline water cultures.

COMPARISON OF RESULTS WITH DIFFERENT SPECIES.

The results obtained for the lupines by Kearney and Cameron and those for maize by Kearney have frequently been referred to in the foregoing pages. It has been possible to compare them to the writer's results with wheat only in a fragmentary way. Since there are some very surprising differences in the toxicity of the same salts to the three plants, the results have been brought together in one table for comparison. Kearney and Cameron used but one variety of the lupine and of maize, their results being shown in the following table. The writer in his experiments on wheat has used nine different varieties, but in the following table only the mean resistance of all the varieties has been taken.

The limit of concentration of the salts which can be endured by wheat, lupine, and maize is as follows, the results being stated both in fractions of a normal solution and in parts of salt per 100,000 of solution:

Salt.	Degree of concentration.					
	Wheat.		Lupine.		Maize.	
	Parts of a normal solution.	Parts per 100,000 of solution.	Parts of a normal solution.	Parts per 100,000 of solution.	Parts of a normal solution.	Parts per 100,000 of solution.
Magnesium sulphate	0.007	39	0.00125	7	0.25	1,400
Magnesium chlorid	.009	108	.0025	12	.08	384
Sodium carbonate	.01	52	.005	26	.015	78
Sodium bicarbonate	.026	217	.02	167	.05	417
Sodium sulphate	.043	302	.0075	53	.05	353
Sodium chlorid	.054	313	.02	116	.04	232

It is remarkable that while magnesium sulphate is the most toxic to the wheat and the lupine of all the salts used it is the least injurious to maize, being thirty-five times and two hundred times, respectively, more toxic to wheat or lupine than to maize.

Magnesium sulphate and magnesium chlorid differ but little in the concentration necessary to kill the root tips of wheat seedlings, while a solution of the former only half as strong as the latter is sufficient to kill the lupines in the same length of time. In contrast to this, a solution of magnesium chlorid only about one-third as concentrated as the critical solution of magnesium sulphate is the strongest that can be endured by the root tips of maize, the order of toxicity of the two salts being reversed. The root tips of the lupines have been killed by every salt used, at a less concentration than that which can be endured by wheat and maize, a solution of sodium carbonate one-half and one-third as concentrated as that necessary to kill wheat and maize, respectively, being fatal to the lupine. It will be noticed, however, that the least amount of diversity is evinced by the three plants in the presence of sodium carbonate and sodium bicarbonate.

Wheat and maize show very little difference in resistance to sodium sulphate, but a solution about one-sixth as concentrated as that necessary to kill maize is toxic to the lupine.

It is a very surprising fact that the variation between the three plants is so great. The salts of magnesium which are the most toxic to wheat and lupines are the least toxic to maize, the difference being as is 200 to 1. Maize is on the whole much more resistant to pure salt solutions than is wheat or the white lupine, while the root tips of the lupines are killed by each of the salts at a much less concentration than that necessary to destroy the root tips of wheat seedlings.

Especially interesting results in this connection have been brought out by Cameron and Breazeale [a] with some experiments concerning the action of acids and salts upon maize, wheat, and clover. The salts employed were not the same as those used by the writer, but the results for both the acids and salts are sufficient to show the difference in resistance between different species and also the different action of different salts and acids on the same species.

Cameron and Breazeale found that N/850 and N/600 solutions of acetic and succinic acids, respectively, were the toxic limit for seedlings of maize, but wheat and clover in the same acids would endure only N/20000. They found the variations in salt solutions to be equally as great, but in some ways reversed. In potassium chlorid the toxic limit for wheat and clover is the same, each having a greater concentration than that necessary to kill seedlings of maize. In potassium oxalate, wheat was found to endure a concentration six times as great as that for clover. It is interesting to note here that the more toxic the acids the more uniform are the results, while for the salt solutions the reverse is true. The writer obtained similar results for the salts used in the experiments described in this paper.

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[a] The Toxic Action of Acids and Salts on Seedlings, Journal Phys. Chem., vol. 8, No. 1, p. 1 (January, 1904).

ASH ANALYSES.

To determine whether or not the amount or the composition of the ash in the seed could be correlated with the resistance of the seedlings to saline solutions, analyses of seeds of each variety used and of the same origin as those used in the culture experiments were obtained through the Bureau of Chemistry of the Department of Agriculture. The results fail to show any correlation between the ash constituents of the seeds and the resistance of the seedlings in water cultures. As the absence of such correlation is important, the table of analyses is inserted. It is a surprising fact that some of the ash constituents run very low for varieties such as Padui and Kharkof, in which one would expect them to be high.

Table of analyses of the ash constituents of wheat seedlings.

Variety.	H_2O.	Crude ash.	CO_2.	MgO.	K_2O.	Na_2O.	P_2O_5.	SO_3.	Cl.
Zimmerman	8.34	1.72	0.080	0.22	0.45	0.050	0.85	0.037	0.054
Kharkof	8.25	1.35	.066	.18	.41	.050	.56	.040	.054
Padui	8.72	1.40	.048	.18	.43	.052	.57	.040	.042
Kubanka	7.68	1.93	.064	.22	.53	.056	.93	.043	.054
Turkey	7.54	1.73	.064	.20	.51	.046	.78	.041	.054
Maraouani	9.70	1.66	.028	.15	.51	--------	.70	.043	.054
Budapest	8.38	1.91	.048	.21	.53	.042	.94	.040	.054
Preston	8.48	1.35	.040	.23	.47	.045	.97	.057	.054
Chul	7.78	1.98	.088	.28	.50	--------	.78	.042	.054

INDIVIDUAL VARIABILITY.

Individual variation within the different varieties is a subject deserving some attention in this connection. Some very striking instances have been noted during the course of these experiments. Since it has been demonstrated beyond dispute that the varieties differ one from another in resistance to toxic salts, it is only natural to suppose that the individuals of the same variety would show diversity in this respect. It is the existence of this individual variability that has made it impossible to obtain reliable results without testing a large number of seedlings. As soon as this factor was eliminated it became comparatively easy to establish the toxic limit. In some instances it was more difficult than in others, and some varieties were especially troublesome in this respect. The reasons for this are difficult to determine.

No experiments have been conducted for the exclusive purpose of demonstrating the range of individual variation, and only results are here recorded which have been brought out incidentally during the tests for varietal variation. The writer does not doubt that experiments with this end in view would bring out instances of individual variability much more striking than any so far obtained. Nearly all varieties, however, have shown exceeding diversity in the

resistance of individual plants, and it will be interesting to mention a few of them. In the experiments to determine the toxic limits for the different varieties the results were based on averages, e. g., in a solution of sodium carbonate of a concentration that was taken to represent the toxic limit 23 seeds were alive in a 0.01 solution and 27 dead. It is not known how many of those seedlings which were alive might have survived in a solution still more concentrated, perhaps of twice the strength, nor is it known how many of those that were killed would have been killed in a solution only half as concentrated.[a]

Instead of making tables to show the individual variation, as was first suggested, only striking instances will be referred to under the names of the different varieties. A series of tables would require more space than can here be given to the subject.

Budapest.—In connection with the experiments with the Budapest variety two striking instances have been noted, one with sodium bicarbonate and the other with magnesium sulphate. The toxic limits for these two salts are 0.025 and 0.01 of a normal solution, respectively. In one experiment, out of a number of seedlings in 0.015 normal sodium bicarbonate two died. In the case of magnesium sulphate, in one experiment all the rootlets were dead in 0.015 normal except one, which survived. Here are two instances with remarkable extremes. In the former case the two seeds were of exceedingly low vitality, while in the latter instance one seed had remarkably great vitality.

Chul.—No very marked individual variations presented themselves during the experiments with the Chul variety.

Turkey.—Few remarkable variations were observed with the Turkey variety. But one instance deserves special attention. The average toxic limit in magnesium sulphate is 0.01 normal, but in a number of tests a few seedlings were readily killed in a solution only half as concentrated as the solution in which one-half of the total number of individuals exposed to it survived.

Preston.—The experiments with magnesium salts brought out two interesting cases with the Preston variety. The toxic limit for this

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[a] Moore and Kellerman (Bul. 64, Bureau of Plant Industry, U. S. Dept. of Agriculture) have given some excellent instances of individual variability with respect to resistance to toxic agents. They have made numerous experiments with copper sulphate upon different algæ which are found in water supplies. They found that 1 part of copper sulphate to 2,000 of water was sufficient to kill one-half of the individuals of *Chlamydomonas piriformis* exposed to it in two days, while the same concentration was sufficient to kill only one-tenth of the same form in three following days, and in three other days only one-fourth. With *Desmidium swartzii* 1 part of copper to 100,000 was sufficient to destroy one-half and three-fourths, respectively, of the individuals involved in two different sets of experiments. Numerous other instances might be cited, but these will suffice to show that individual variation in this respect is not confined to wheat alone.

variety with both the chlorid and the sulphate of magnesium is 0.005 normal. In both salts, however, rootlets of some of the plants survived in solutions twice as concentrated. In the case of magnesium chlorid, 8 out of 25 survived, while with the sulphate only 2 out of the same number survived.

Kharkof.—In solutions of sodium chlorid and sodium sulphate of a concentration of 0.045 and 0.035 normal, respectively, one seedling of the Kharkof variety was dead in each, the limits fixed for these two salts being 0.055 and 0.0425. The root tips of two seedlings were killed in 0.02 normal of sodium bicarbonate, for which the average toxic limit is 0.03.

Zimmerman.—The Zimmerman variety, while the most resistant of all, shows some very marked individual variation. A striking instance occurred with magnesium chlorid, the average toxic limit of which is 0.015 normal. In a solution one-third as concentrated (0.005 normal) 2 seedlings out of 20 could not survive. The limit of concentration for this variety in sodium chlorid is 0.065 normal, but the rootlets of one seedling could not survive in 0.045. Similar to this are the results with sodium sulphate, the toxic limit being 0.05, but the root tips of two individuals did not survive in 0.035 normal solution.

Padui.—No variation of any importance.

Maraouani.—The rootlets of two seedlings of the Maraouani variety were killed in 0.005 normal magnesium sulphate, while 3 out of 20 individuals survived in 0.015. The average toxic limit for this salt is 0.0075 of a normal solution.

Kubanka.—No important variations.

NEUTRALIZING EFFECT OF THE SALTS EMPLOYED UPON OTHER TOXIC SUBSTANCES.

Because of a discovery which was made when these experiments were almost completed it is necessary to add a few remarks upon the neutralizing effect upon other toxic substances of the salts of sodium and magnesium. During the whole course of the experiments the writer was unable to get seedlings to grow or even to live for twenty-four hours in the distilled water used. This seemed unaccountable, as it quite disagreed with the results of other experimenters. Coupin found the roots of wheat seedlings to thrive well in perfectly distilled water, and Dehérain and Demoussy[a] showed absolutely pure water to be perfectly harmless to root growth. Numerous experiments have been made to determine this point, with more or less varying results. Certain experimenters have held that distilled water was not conducive to good growth.

[a] Sur la Germination dans l'Eau Distillé,' Compt. Rend., Paris, 132: 523 (1901).

This is probably an error so far as young seedlings are concerned. The seed contains everything necessary for the early growth of the plant, and the absence of all minerals or other nutrient compounds in the surrounding solution should produce no bad effect during the earliest stages of growth. Those who claim that distilled water is injurious will probably find, upon closer observation, that it is some injurious substance in the water which is really toxic to the roots. In the case of many plants one of the most toxic substances known is copper, and it is more than likely that it is present in much of the water which experimenters have found to be injurious. Coupin states that one part of copper to 700,000,000 of water is sufficient to retard the root growth of wheat seedlings. A mere trace of copper is sufficient to retard growth in many cases.

As a result of an analysis made in the Bureau of Chemistry of the Department of Agriculture of the distilled water used in these experiments, it was found to contain a considerable quantity of zinc, but no trace of copper. The harmful effect probably should be attributed to zinc alone. The water used in these experiments was distilled but once, and was collected in a porcelain tub as a receiver.

It was thought while the work with wheat seedlings was in progress that copper or zinc might be the cause of the injurious effects, but the writer used the water from the same still for all experiments with *Lupinus albus*, and no toxic effect of the distilled water was noticeable. Control checks with lupines were carried in both distilled and hydrant water, and no difference was found in the rate of growth. It was this observation which at the outset of the work with wheat gave the writer confidence in the quality of the distilled water. This is apparently another indication that different species of plants vary greatly in their ability to resist the influence of toxic salts. Wheats are apparently much more sensitive than lupines to pure solutions of zinc salts, although much less sensitive to pure solutions of sodium and magnesium salts.

At first thought one would conclude that since the distilled water used contained harmful substances the experiments above described are practically without value; but such is not the case, as will be seen before this discussion is completed. In order to compare closely the water used during most of the experiments with absolutely pure water, some experiments were made. To secure absolute purity in the water a new still was made of the best nonsoluble glassware, having no metal in any of its parts. The same water that had been previously used was redistilled for the purpose. The wheat seedlings were treated in every way as before. A control was also carried in Potomac River water for comparison, and each lot of seed was taken up each day and the elongation of the roots measured and recorded for four consecutive days. In the twice-distilled water they grew

about as well as in hydrant water. In order to show to what extent the impurity of the water used would affect former experiments, salt solutions of a dilution far below the toxic limits, as already established, were made, using the water which was but once distilled. The results showed that the toxic element in the water was effectively neutralized by the addition of even minute quantities of any one of the salts used in the experiments. For comparison equal numbers of seeds were tested at the same time in the water distilled twice, in that distilled but once (that used throughout the above-described experiments), and in dilute salt solutions made up with the once-distilled water.

The following table embodies the results obtained with very dilute solutions of the salts, with distilled water, and with hydrant water:

Water or solution.	Elongation of roots at the end of a given time.			
	First day.	Second day.	Third day.	Fourth day.
	mm.	*mm.*	*mm.*	*mm.*
Water distilled once	2.2	2.2	2.2	2.2
Water distilled twice	11.4	26.2	33.7	36.3
Magnesium sulphate (0.001 normal)[a]	10.6	21.2	27	27.6
Magnesium chlorid (0.001 normal)[a]	16.8	30.8	37.6	38.2
Sodium carbonate (0.001 normal)[a]	11.3	14.5	16.8	17.8
Sodium bicarbonate (0.0075 normal)[a]	10.6	24	31	32.4
Sodium sulphate (0.015 normal)[a]	8.5	22	31.5	34.8
Sodium chlorid (0.015 normal)[a]	7.8	15	19	22
Hydrant water	9.4	23.8	37.4	46

[a] The mean toxic limit of all varieties of wheat tested in the presence of the salts here employed is shown as follows:

	Parts of normal solution.
Magnesium sulphate	0.00736
Magnesium chlorid	.00931
Sodium carbonate	.0109
Sodium bicarbonate	.026
Sodium sulphate	.0432
Sodium chlorid	.0542

A comparison of these figures with the table above shows that from one-third to one-tenth the concentrations of the solutions which represent the limit of endurance of the wheat varieties is sufficient to neutralize the harmful effect of the zinc present in the distilled water.

The above table shows that after an elongation of 2.2 mm. during the first day in the water distilled once no further growth took place. A comparison of that with absolutely pure water (in this case redistilled) shows that there was some element in the first water which hindered growth and which was not found in the second. This, as the chemical analysis above referred to showed, is probably zinc.

The results in the dilute salt solutions which were made up with the injurious once-distilled water showed that there was no material difference in the elongation made in them and in the checks in redistilled and hydrant water. It is not assumed that these dilute solu-

tions were in the exact proportion that would have permitted the greatest elongation. The object was merely to show that at the concentrations used in these experiments the salts of magnesium and of sodium effectively neutralize the injurious element present in the once-distilled water. The only noticeable difference was in the case of sodium carbonate and sodium chlorid, in which the elongation was somewhat below the average in the pure-water check and in the solutions of other salts. The use of a more dilute or a more concentrated solution would doubtless have removed this difference. On the other hand, a 0.001 normal magnesium chlorid was conducive to better development than any of the others, with the single exception of hydrant water. It will be noticed that at the end of the third day there was even a slight advantage in favor of magnesium chlorid over river water.

The elongation the fourth day was but a slight increase over that at the end of the third, with the one exception of the seeds in the hydrant water. This is just what was to be expected. During these four days the seeds were compelled to live on the nutriment stored up in the endosperm. This had been practically all used up at the end of the third day; hence the cessation of growth. With hydrant water the conditions were different. Certain nutritive substances are contained in this water upon which the roots can draw when those contained in the endosperm have been exhausted.

In view of the experiments, small quantities of these sodium and magnesium salts, instead of being injurious when present in the soil, might be actually beneficial in case the soil contains very toxic substances, e. g., zinc or copper. In fact, these salts are injurious only when present in excessive quantities, as in the so-called "alkali soils" of the West.

DILUTE SOLUTIONS AS STIMULANTS.

Incidentally, throughout these experiments, evidences of stimulation in dilute solutions were obtained. This has been shown to occur by many investigators with other salts and with some acids.[a]

Kearney and Cameron, who made similar observations when experimenting with *Lupinus albus*, say:

> In the case of certain salts, when plants are exposed to pure solutions which are much too dilute to produce any toxic effect, there occurred a decidedly

[a] Some fungi have been known to be stimulated by the presence of small quantities of poisons. The germination of spores has likewise been hastened when in the presence of acids or salts. Townsend (Bot. Gaz., 27: 458–466, 1899) found that the germination of various seeds and spores has been stimulated by the presence of traces of ether, and (Bot. Gaz., 31: 241–264, 1901) that the presence of hydrocyanic acid for a brief period of time accelerates germination and subsequent growth.

stimulating effect upon growth, as compared with that in the distilled water control during a corresponding period. This was shown to be the case for salts of calcium, both the chlorid and the sulphate acting as stimuli.

These investigators found decisive evidence of such stimulating action with both the carbonate and the bicarbonate of sodium. Sodium sulphate and sodium chlorid gave purely negative results. Very marked results of this kind were observed by Cameron and Breazeale when working with acids. Hydrochloric, sulphuric, and nitric acids in concentrations but little below the toxic limit produced enormous stimulation, especially with wheat.

Copeland [a] shows that zinc and copper in water cultures accelerate growth when the solutions are not much more dilute than those that are distinctly toxic. Similar observations have been made by many earlier investigators.

In the experiments with wheat all the salts were found to stimulate growth except sodium chlorid and sodium carbonate, which were indifferent at the lowest concentration used. It is not unlikely, however, that if the proper dilution of the carbonate were employed it would be found to act as a stimulus with wheats just as it did with lupines. In fact, it was found that the same concentration of certain salts which was decidedly toxic for some varieties of wheat will act as a stimulant to another variety. Especially is this true of the chlorid and sulphate of magnesium. In a 0.005 solution of each of these salts the elongation of the roots of Turkey wheat was equal to that in the control of hydrant water during the period of twenty-four hours. The toxic limits for this variety are 0.0075 normal for the chlorid and 0.01 normal for the sulphate. As will be seen, two-thirds and one-half the concentration of the toxic limit, respectively, not only were not toxic but actually acted as a stimulating influence. There is a possibility, in view of these results, that dilutions not very much below the toxic limit are more likely to have a stimulating effect than are much more dilute solutions. This, however, is not a question to be settled at this time, but will require to determine it a series of special experiments.

A 0.015 normal solution of sodium sulphate caused an elongation about one and one-half times as great as that in hydrant water. The same dilution of sodium chlorid gave results somewhat less striking, but the elongation was well above the average of that in the hydrant-water checks.

As before stated, it would seem that instead of being injurious, dilute solutions of these salts might be decidedly advantageous, yet if they cause an unnatural growth their presence must be considered as detrimental rather than beneficial. Copeland calls attention to

[a] Chemical Stimulation and the Evolution of Carbon Dioxide. Bot. Gaz., 35: 81–98 (1903).

this fact, and is of the opinion that substances acting as stimulants are in the long run injurious.

It is of course an established fact that certain of these salts are beneficial and even necessary in particular cases. It has been claimed that chlorids are indispensable to buckwheat. The plant thrives well until it has passed the blooming stage, at a period when potassium chlorid seems necessary to complete the fruiting stage. This fact has apparently been demonstrated by experiment. Loew[a] says that fungi grown in culture solutions containing only traces of magnesia form no spores, but by increasing the amount of lethicin and thus adding more magnesium to the culture solution spores will be formed. Magnesium salts are as indispensable to fungi as to higher plants, but an exceedingly small amount is sufficient when the solution has an acid reaction.

Plants are often benefited by sodium salts.[b] While three of these salts—the chlorid, bicarbonate, and carbonate—are not indispensable to the plant, they accelerate ripening in some of the cereals.

Loew asserts that sodium, manganese, and silicon are often beneficial but not indispensable to phanerogams. Sodium salts are not essential in the physiological processes of plants, but are indispensable to animals.

PRACTICAL VALUE OF RESULTS.

There is certainly a very practical lesson to be drawn from the results described in this paper. It has of course long been known that plants of different genera and species show very different

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[a] The Physiological Rôle of Mineral Nutrients in Plants. Bul. 45, Bureau of Plant Industry, U. S. Dept. of Agriculture (1903).

[b] Chittenden and Wachsman are of the opinion that the conversion of starch into dextrin and sugar (diastase) is more vigorous in the presence of small quantities of sodium chlorid (0.24 per cent). Several investigators, prominent among whom are Sprengel and Liebig, have shown that various crops, and more especially beans, are much benefited by the application of small quantities of common salt.

Pethybredge (Bot. Centralbl., No. 33, 1901) is authority for the statement that the color of wheat leaves is intensified when sodium chlorid is applied.

S. Suzuki (Bul. Coll. Agric., Tokyo, 5: No. 2, p. 199) showed that potassium iodid, even in very high dilutions, exerted a stimulating action on the growth of the pea; and (ibid., No. 4, p. 473) that dilute quantities of potassium iodid stimulated oats. In opposition to these stimulating effects the same investigator has found (ibid., No. 4, p. 513) that vanadin sulphate, even in very dilute quantities, produced little or no stimulating action on barley, though he states that a very weak stimulating action on the roots seemed to have taken place in a 0.01 per mille of vanadin sulphate. He further shows (ibid., No. 2) that potassium ferrocyanid acts as a poison on plants in water cultures even in very high dilutions.

behavior when brought into relation with saline or alkaline soils. But the species itself may include a great number of different varieties or races, as in the case of wheat. It is not enough to know that wheat in general is better adapted to a certain region because of soil or climatic conditions than is Indian corn or cotton, but in addition it is necessary to know which of the many varieties of wheat is best suited to that region. Such knowledge might save many years of constant selection with a view to acclimatization.

Soils are often known to contain sodium chlorid or magnesium sulphate or some other salt in such quantity as to be fatal to some varieties, while permitting others to flourish. Now, it has been possible by these experiments to determine that some varieties of wheat are much more resistant to a particular salt than others, and they are the ones which would be expected a priori to thrive best in a region where that salt predominates, other conditions being equal. By some of the experiments it was found that some varieties would thrive equally well in three times the concentration of sodium carbonate as others. A simple deduction from such results would be that for a region containing large quantities of "black alkali" the variety shown to have the greatest resisting power should be selected.

A knowedge of the limits of individual variation within each variety is likewise very essential. Often the most resistant varieties are not always the most desirable in other respects and a sort which is less resistant would be preferable. In case such a sort has a great individual variation in resistance to salts it should be comparatively easy to introduce it by gradual selection of the most resistant individuals, though a little more time would naturally be required than in introducing a variety that is already more resistant, as a smaller percentage of the plants would survive to furnish seed for the next crop.

It is believed, therefore, that the results of these experiments afford additional proof that the adaptation of useful cultivated plants to saline or alkaline soil conditions is one of the most promising of plant-breeding problems.

SUMMARY.

(1) The salts with which the experiments were made are injurious to wheat seedlings in the following order: Magnesium sulphate, magnesium chlorid, sodium carbonate, sodium bicarbonate, sodium sulphate, and sodium chlorid. This is asserted as true only of wheat, and a quite different order might possibly be established for other plants.

(2) The results obtained from a few individual seedlings are inaccurate and unreliable. A large number must be tested in order that

individual variation may be eliminated. Usually about ten days of experiment and from 60 to 100 seedlings were employed to establish the toxic limit for each variety in each salt.

(3) Wheat is one and a half to six times as resistant as white lupines, according to the salt used. In sodium bicarbonate the least and in magnesium sulphate and sodium carbonate the greatest difference in resistance between these two plants is shown.

(4) Different varieties, representing the two extremes, vary in the ratio of 1 to 3 in their resistance to the toxic effect of different salts. This is especially true for sodium carbonate and magnesium chlorid. In magnesium sulphate they vary in the ratio of 1 to 2.

(5) The variety most resistant as a whole is not necessarily the most resistant to every salt. The variety that averages least in resistance may be twice as resistant to some one particular salt as that which averages highest. In this fact may be found the secret of selecting a variety for a locality where the soil contains an excess of some one salt.

(6) The least resistant variety is not always the least resistant for every salt used. It may be exceedingly resistant to one or more salts and yet have a very low sum total resistance.

(7) It is not possible from the results with a few varieties to draw general conclusions for all sorts of wheat. Each will have to be worked out for itself.

(8) Varieties which come from localities where saline salts abound are the most resistant in water cultures to these toxic salts. Varieties from humid regions are less resistant.

(9) In general, the more toxic the salt the greater is the ratio of resistance of one variety to another. The less toxic the salt the smaller is the ratio. For sodium carbonate and magnesium chlorid the ratio of resistance is greatest, being as 1 to 3. For the remaining salts it is smaller.

(10) Individual variation is more prevalent and makes the establishment of the toxic limit much more difficult in some varieties than in others.

(11) All the salts used act as stimulants in dilute solutions except sodium carbonate and sodium chlorid, which were neutral even in very dilute solutions. In some cases the elongation in dilute solutions was nearly twice that occurring in the controls of hydrant water.

(12) Absolutely pure distilled water does not hinder development, but traces of zinc are sufficient to kill the root tips in twenty-four hours.

(13) The economic importance of these results is based upon the fact that water-culture experiments may be a means for saving several years of selection by indicating whether a certain variety is adapted to soil conditions in a particular region.

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